



***Adaptive Modulation Schemes for OFDM and
SOQPSK Using Error Vector Magnitude (EVM)
and Godard Dispersion (Brief)***

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Adaptive Modulation Schemes for OFDM and SOQPSK Using Error Vector Magnitude (EVM) and Godard Dispersion

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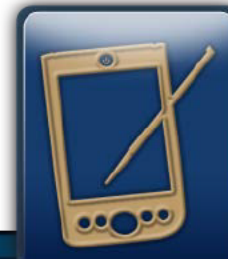
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Environment



Outline

- Project objective
- Motivation
- Modulation schemes
 - SOQPSK
 - OFDM (BPSK, QPSK, 16QAM and 64QAM)
- Link metrics
 - Error Vector Magnitude (EVM)
 - Godard dispersion
- Relationship between EVM and Godard dispersion
- Simulation results
- Conclusion and future work

Project Objective

Develop and test a prototype system that adapts its modulation/coding scheme based on channel conditions in a telemetry environment (LDAR).

- Include SOQPSK and OFDM
- FEC types/rate

Test Article



Transmit Data Using Mode Identified by GS

Picture from:

<http://www.navair.navy.mil/index.cfm?fuseaction=home.PhotoGalleryDetail&key=DED6B9E2-5DC2-4711-9D67-BE0B29C0DAD7>

Estimate Channel
Select Transmit Mode



Ground Station

Illustration of airborne telemetry environment



Motivation

- **Question:**

How to enable adaptation across two modulation schemes of OFDM and SOQPSK?

- **Possible Approaches:**

- Find a common metric that applies for both OFDM and SOQPSK
- Find the relationship between two distinct metrics that we choose for OFDM and SOQPSK

Modulation Schemes

- SOQPSK

The modulated signal:

$$x(t) = \sqrt{\frac{E_b}{T_b}} \exp[j(\phi(t, \alpha) + \phi_0)]$$

where E_b is energy per bit, T_b is the bit duration, ϕ_0 is an arbitrary phase that will be set 0 for this work, and the information carrying phase is given by

$$\phi(t, \alpha) = 2\pi h \int_{-\infty}^t \sum_{n=-\infty}^{\infty} \alpha_n g(\tau - nT_b) d\tau$$

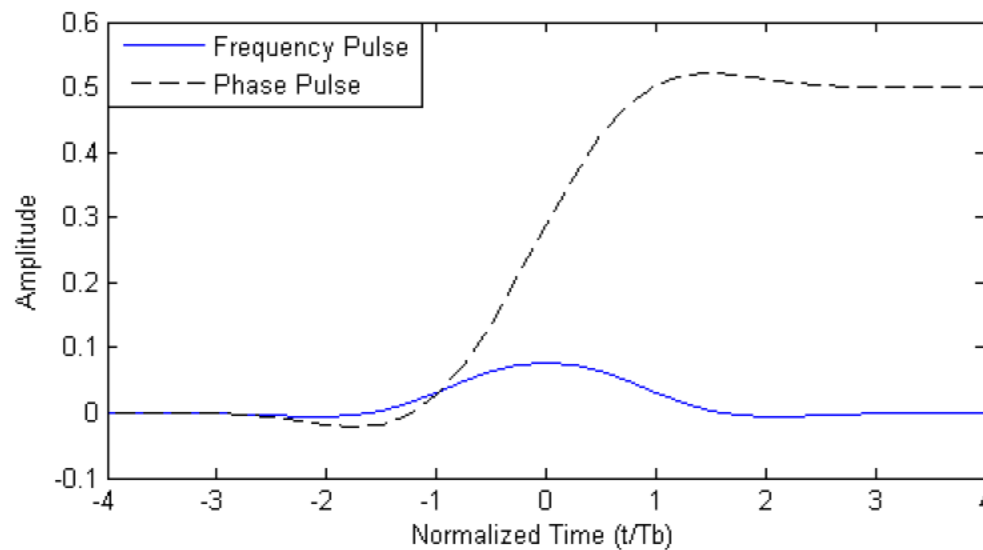
where $g(t)$ is the frequency pulse, $h = 1/2$ is the modulation index, and $\alpha_n \in \{-1, 0, 1\}$ are the ternary input symbols, which are related to the binary data bits $b_n \in \{0, 1\}$ by

$$\alpha_n = (-1)^{n+1} (2b_{n-1} - 1)(b_n - b_{n-2})$$

The telemetry version SOQPSK-TG, which is partial-response with pulse duration of $L = 8$ and a frequency pulse given as

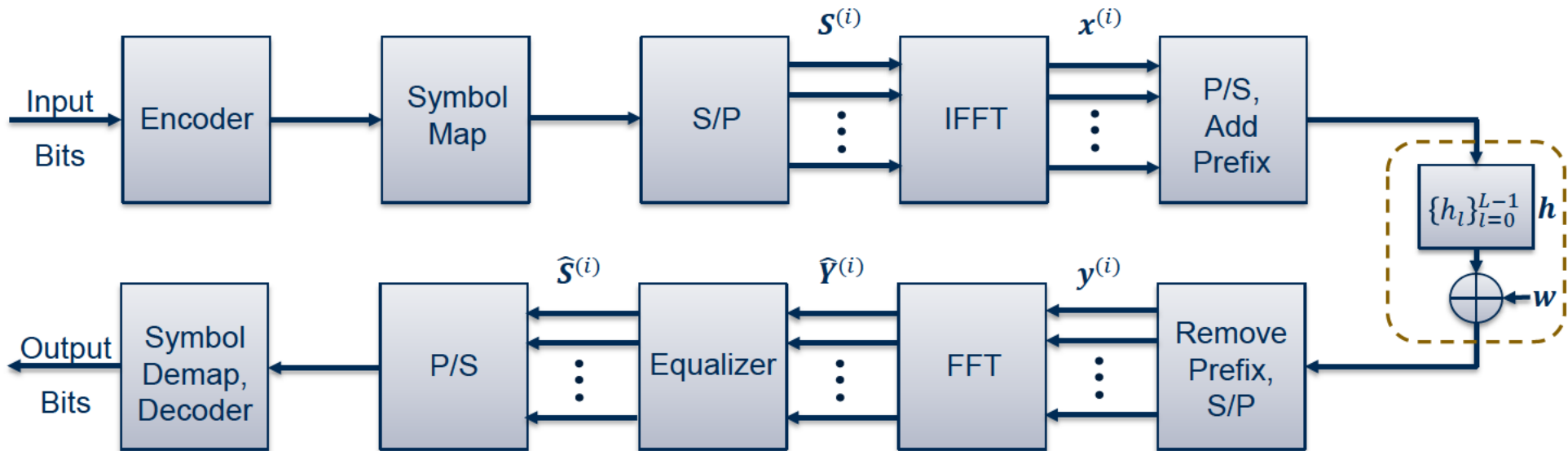
$$g(t) = C \frac{\cos\left(\frac{\pi\beta_1\beta_2 t}{2T_b}\right) \sin\left(\frac{\pi\beta_2 t}{2T_b}\right)}{1 - 4\left(\frac{\beta_1\beta_2 t}{2T_b}\right)^2 \frac{\pi\beta_2 t}{2T_b}} w(t)$$

According to the iNET standard, $\beta_1 = 0.7$, $\beta_2 = 1.25$, $T_1 = 1.5$, $T_2 = 0.5$, and the constant C is chosen to give $g(t)$ an area of $1/2$. The frequency pulse and the corresponding phase are shown in the following figure:



• OFDM

The OFDM implementation is illustrated in the following diagram:



where $\mathbf{s}^{(i)} = \{s_k^{(i)}\}_{k=0}^{N-1}$, i is OFDM block index, k is QAM symbol index in each OFDM block, and N is the number of sub-carriers.

$$\hat{\mathbf{s}}^{(i)} = \mathbf{s}^{(i)} + \mathbf{H}^{-1} \tilde{\mathbf{w}}$$

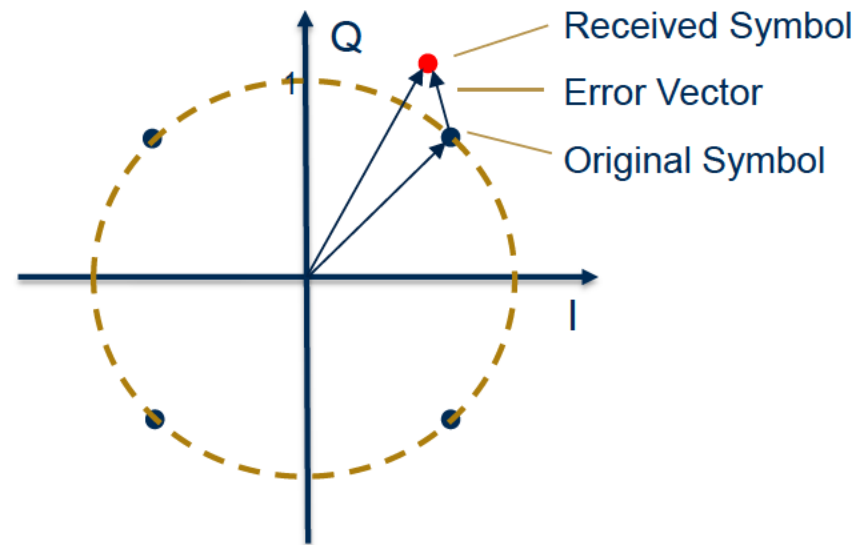
where $\mathbf{H} \triangleq \text{diag} \left(\text{FFT} \begin{bmatrix} \mathbf{h} \\ \mathbf{0}_{N-l} \end{bmatrix} \right)$ and $\tilde{\mathbf{w}} = \text{FFT}\{\mathbf{w}\}$.

Link Metrics

- EVM

EVM measures the deviation of the received symbols from their original transmitted positions in the I/Q plane. The following figure shows the normalized constellation diagram for QPSK with one received symbol.

$$\text{EVM}_{\text{RMS}} = \left[\frac{\frac{1}{N_s} \sum_{i=1}^{N_s} |S_{r,i} - S_{o,i}|^2}{\frac{1}{N_s} \sum_{i=1}^{N_s} |S_{o,i}|^2} \right]^{\frac{1}{2}}$$



where $S_{r,i}$ is the received symbol, $S_{o,i}$ is the original transmitted symbol, and N_s is the number of symbols over which EVM is averaged.

In this work, we use $\text{EVM} = (\text{EVM}_{\text{RMS}})^2$.



- **Question:**

Does EVM apply to SOQPSK?

- Yes or No?

- SOQPSK is Continuous Phase Modulation (CPM)
- Demodulation using Viterbi decoder or similar decoding method
- No single symbol soft decision

- If not, which metric can we choose for SOQPSK?

- Godard dispersion measures the width modulus error of a constant modulus signal
- For the CPM point of view, we choose Godard dispersion

- Godard Dispersion

Godard dispersion function was first proposed by Godard, and is defined as

$$D^{(p)} = E \left[(|y_n|^p - R_p)^2 \right]$$

$$R_p \triangleq \frac{E[|x_n|^{2p}]}{E[|x_n|^2]}$$

where x_n is the input symbol, y_n is the received symbol, R_p is a constant depending only on the input data constellation, p is an integer. In this paper, we use $p = 2$.

Therefore, the second-order Godard dispersion for SOQPSK is defined as

$$D^{(2)} = E[(|y_n|^2 - 1)^2]$$



Relationship between EVM and Godard Dispersion

- We can derive Godard dispersion for SOQPSK, EVM for OFDM as follows:

$$D^{(2)} = 2 \sum_{l=0}^{L-1} \sum_{p=0}^{L-1} |h_l|^2 |h_p|^2 - \sum_{l=0}^{L-1} |h_l|^4 + 2\sigma_w^4 + 2\sigma_w^2 - 1$$

$$\text{EVM} = \sigma_w^2 \frac{1}{N} \sum_{jj=1}^N |H_{jj}^{-1}|^2$$

where H_{jj} is the diagonal element of \mathbf{H} , which is the frequency-domain channel response of the j^{th} sub-carrier, h_l is channel impulse response, and σ_w^2 is the variance of channel noise.

- Thus we obtain the mapping between EVM and Godard dispersion:

$$D^{(2)} = 2 \sum_{l=0}^{L-1} \sum_{p=0}^{L-1} |h_l|^2 |h_p|^2 - \sum_{l=0}^{L-1} |h_l|^4 + 2 \left[\left(\frac{\text{EVM}}{\frac{1}{N} \sum_{jj=1}^N |H_{jj}^{-1}|^2} \right)^2 + \frac{\text{EVM}}{\frac{1}{N} \sum_{jj=1}^N |H_{jj}^{-1}|^2} \right] - 1$$

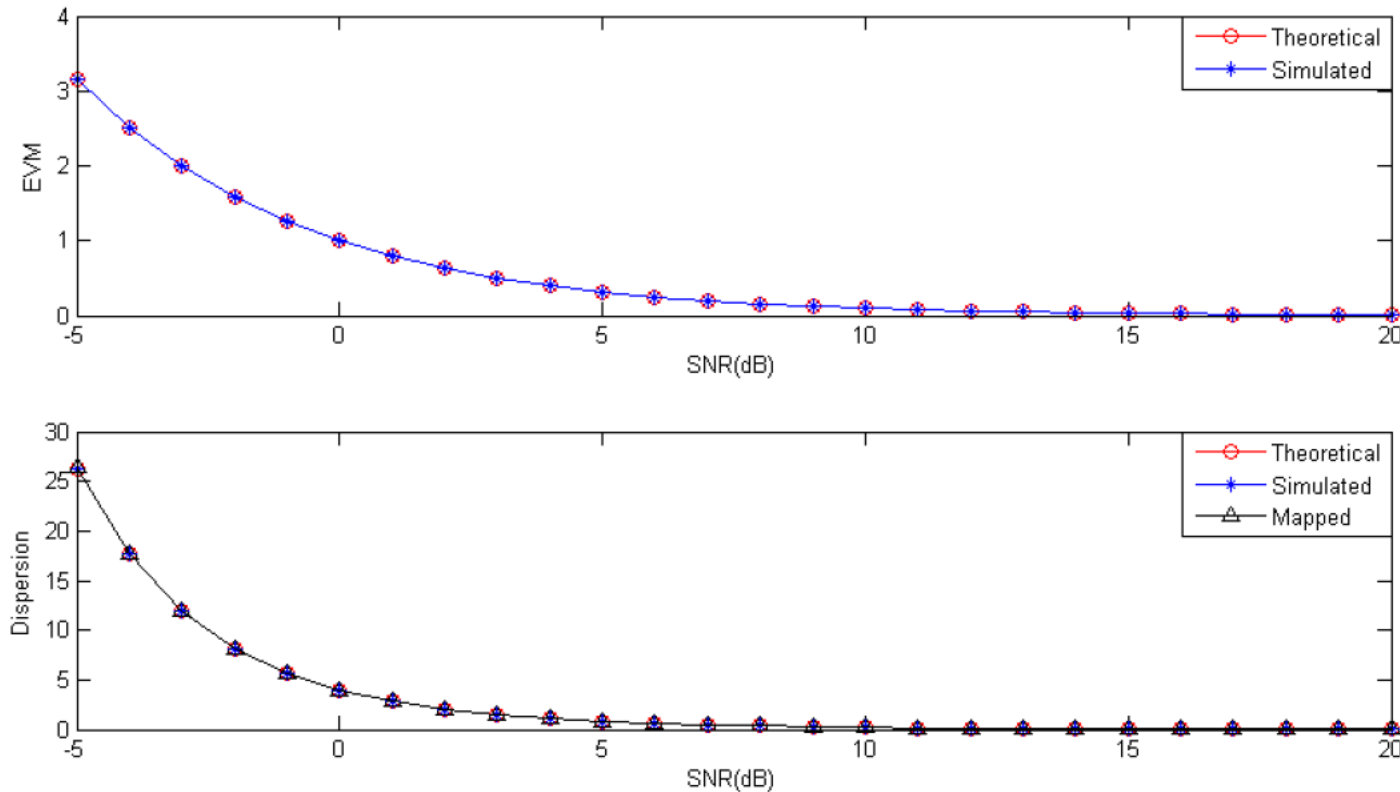


Simulation Results

Compare theoretical mapping to metrics computed from time-domain simulated data using an AWGN channel.

- The simulation results were obtained using 2/3 LDPC code rate.
- The EVM values were calculated using OFDM/QPSK with 64 sub-carriers.
- Both EVM and $D^{(2)}$ were simulated using 100 iNET bursts, each burst consists of 49152 coded bits (8 LDPC codeblocks).

SNR(dB)	EVM		Godard Dispersion ($D^{(2)}$)		
	Theoretical	Simulated	Theoretical	Simulated	Mapped from EVM
-5	3.1623	3.1642	26.3246	26.3318	26.3525
0	1.0000	0.9993	4.0000	3.9968	3.9960
15	0.0316	0.0316	0.0652	0.0652	0.0652



- It can be seen from the figure that the simulated EVM and $D^{(2)}$ are both very close to the theoretical data.
- The average percentage error between “mapped $D^{(2)}$ from EVM” and “theoretical $D^{(2)}$ ” is only about 0.0682%.



Conclusion and future work

- Derived the mathematical mapping from EVM to second-order Godard dispersion, which enables the adaptation across two modulation schemes: OFDM and SOQPSK.
- Verified our mapping using an AWGN channel with experimental results very close to theoretical results.
- Future work will integrate this mapping to our adaptation rules, test using representative channel models we have developed, then implement these rules in hardware and test in real wireless channels.



Questions?